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EFFECT OF TEMPERATURE ON THE TENDERNESS OF COOKED BEEF

Interim Report

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QUARTERMASTER FOOD AND CONTAINER INSTITUTE FOR THE ARMED FORCES
QUARTERMASTER RESEARCH AND ENGINEERING COMMAND, U.S. ARMY
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 pp 24 tbi 5 fig. 3

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QMFCIAF REPORT NO. 28-62

PROJECT: 7-84-06-032
Development

Effect of Temperature on the Tenderness of Cooked Beef

Interim Report

by

J. M. Tuomy, R. J. Lechnir, Terrance Miller

Meat Products Branch

Food Division

August 1962

Quartermaster Food and Container Institute for the Armed Forces

EFFECT OF TEMPERATURE ON THE TENDERNESS OF COOKED BEEF

SUMMARY

This report shows that the degree of tenderness of beef attained through cooking is dependent upon the inherent tenderness of the meat, time, and temperature. The initial effect of heat is toughening due to protein coagulation progressively occurring as the temperature increases. Tenderization of the coagulated protein is a function of temperature and time with little or no tenderization taking place below 180^oF. There was no evidence in this study that connective tissue played any part in the toughness of the meat although this probably would not hold true for different cuts.

Kramer shear press results correlated highly with panel results for tenderness and cuttability.

The work reported is part of a larger study on organoleptic properties of freeze-dried meats and how to measure them objectively.

EFFECT OF TEMPERATURE ON THE TENDERNESS OF COOKED BEEF

In a previous study concerned with pre-dehydration variables of cooked, sliced, freeze-dried beef (1), it was found that cooking was the principle variable of those investigated affecting tenderness of the rehydrated product. However, it became evident during the study that the degree of tenderness obtained probably was dependent upon the degree of cooking or a function of both time and temperature. Thus, the cooking cycle would be the determinant factor rather than just the internal temperature to which the meat is heated. The current study was designed to investigate the effect of time at various temperature levels on the tenderness of cooked beef. It is part of a larger study on the organoleptic properties of freeze-dried meats and the development of objective tests for measuring them. The studies are being undertaken to develop improved acceptability of meats procured for Armed Forces operational rations such as the Quick-Serve meal within current industry capabilities and without undue cost increases.

The literature on the tenderness of beef is quite extensive. Much of it is concerned with precooking factors such as breed, feeding, and grades as well as differences in tenderness within given muscles and between muscles. Many of these investigations showed significant correlations. However, under present meat industry practices in this country it would be a practical impossibility to utilize most of the findings in Government procurements. As a practical matter, then, considerations in this study are limited to factors which can be controlled under present industry practices without excessive cost increases. It is

recognized that the inherent tenderness of the meat as used can, and probably will, vary widely, not only from piece to piece, but also from muscle to muscle and even within a given muscle.

In a majority of the investigations on tenderness reported in the literature, the criteria for the degree of cooking has been the internal temperature to which the meat is heated. This follows the popular criteria for doneness in beef which relates it to the color of the cooked beef. The three general classifications used, rare (raw meat color), medium (pink), and well done (grey), are primarily the result of the temperature to which the meat is cooked. The criteria are subjective and the temperatures chosen by different investigators vary. For example, Satorius and Child (2) used 58°*C*. (136.4°*F*.), 67°*C*. (152.6°*F*.), and 75°*C*. (167°*F*.), whereas Visser et al (3) used 55°*C*. (131°*F*.), 70°*C*. (158°*F*.), 85°*C*. (185°*F*.), for the three classifications. Many investigators have minimized or ignored factors which would determine the heating and cooling cycles such as piece dimensions and conformation. Thus, they have excluded time at a given temperature as factors in tenderness of cooked beef and many of the reported conclusions are in some doubt if time as well as temperature determine the degree of tenderness.

Clark et al (4) state that the internal temperature to which the meat is cooked rather than the method of cooking is important to tenderness. However, Lowe (5) states that under most conditions the time of cooking rather than the cooking temperature appears to be the determining factor affecting tenderness. Clark and Van Duyne (6) in comparing top round roasts cooked in an oven and in a pressure saucepan to an internal temperature of 82°*C*. (179.6°*F*.) found the cooking time in the

pressure saucepan to be 1/3 less but found no difference in tenderness ratings or shear press values.

The reactions which take place during the cooking of meat are not well understood in their relationship to the final tenderness of the meat. Cover (7) states that there are two structures in meat which contribute to its toughness -- muscle fiber and connective tissue. Visser et al (3) state that among other things, such as aging before cooking, heat coagulation of muscle fiber proteins and partial hydrolysis of connective tissue are factors in the resulting tenderness of cooked meat. Heat coagulation of muscle fiber proteins would cause toughening and partial hydrolysis of connective tissues would cause tenderization. Winegarden et al (8) in working with connective tissue, state that the comparatively short times in which connective tissue softens under the influence of heat suggests that the long cooking times, such as used in stewing are necessary to soften coagulated fibers rather than connective tissues alone. Furthermore, there was almost no tenderization of the connective tissue until a temperature of 65°^OC. (149°^OF.) was reached although it proceeded rapidly thereafter. Tischer et al (9), in an investigation of canned beef, found that the shear values started out relatively small, increased to a maximum, and then fell off gradually as time progressed with this trend increasing at a more rapid rate as the process temperature was increased. In earlier work with canned beef, Bard and Tischer (10) found that the rate of change in the tenderness of canned beef was proportional to the processing temperature and the times required to reach a minimum shear force at each processing temperature appeared to be approximately linearly related to the

temperature employed. Cover (7), in investigating the effect on tenderness of beef roasts of extremely slow rates of heat penetration, reported that roasts were always tender when the rate of heat penetration required 30 hours or more for the meat to lose its red color. Bramblett et al (10) reported that roasts cooked at an oven temperature of 63°C. (145°F.) for 30 hours were significantly more tender than those cooked for 18 hours with an oven temperature of 68°C. (155°F.).

All of the studies above were done with masses of meat which necessitated distinct come-up and come-down times during which the meat was subjected to cooking cycles which varied widely. This study was undertaken to determine the effect of given temperatures on the tenderness of beef. Thus, the cross section of the meat used was made small enough to permit rapid temperature changes throughout the entire piece. At the same time the cross section was large enough so that discs of uniform thickness could be cut and evaluated for tenderness and cuttability by a panel.

Experimental Methods

Canner/Cutter inside rounds were received in the fresh, chilled state with no control of quality other than grade and condition. Immediately upon receipt the semi-membranosus muscle was removed, trimmed of surface fat and connective tissue, shaped, and frozen in a -20°F. blast freezer. The following day the frozen meat was cut on a meat saw into "logs", 1½ inch square and about 8 inches long. The logs were mixed to insure randomization, individually wrapped in waxed paper, and stored at 0°F. until needed.

Stainless steel tubes measuring 7/8 inch internal diameter and eight inches long open at both ends were used for cooking. The meat logs were tempered at 75 to 80°F. for about 1/2 hour and then carefully cut down until they fit tubes tightly. Thermocouples were inserted through holes in the center of the tubes and the wires taped to the tubes to hold the couples in place.

Cooking temperatures used were 140, 160, 180, 190, 200, and 210°F. Zero time would be when the sample was just brought up to run temperature. Five runs were made at each temperature. Sufficient tubes for a given run were placed upright in a wire basket which was then placed in a kettle of water at 20°F. above the temperature to be investigated. For run temperatures of 200° and 210°F. the come-up water was at 210°F. As soon as the internal temperature of the meat reached the run temperature, the basket was transferred to a kettle containing circulating water held at the run temperature. Tubes were removed at time intervals and immediately placed in 32°F. water. Come-up time varied from three to eight minutes depending upon the temperature. Come-down time to less than 100°F. was three minutes or less.

The cylinders of cooked meat were held overnight in a 40°F. cooler and then cut into $\frac{1}{4}$ -inch thick discs. Discs with gristle, excess fat, and any other defects were discarded.

Evaluation of the product was accomplished by a panel of 10 technologists rating the discs for tenderness, cuttability, and flavor on 9-point scales where the higher the number the more tender, more cuttable, or more flavorful the judgment.

A Kramer Lee shear press Model SP21 with a Westronics recorder was used to obtain the shear press results. Six of the meat discs were placed in the Kramer cell for each test with triplicates being run for each sample. A downstroke of 30 seconds and a 3000 pound ring were used with the Kramer. Results were reported as pounds pressure measured at the peak of the shear value.

Previous work (1) has indicated that the quality of the meat going into the freeze-drying process will determine the quality of the finished product. Freeze-drying will not tenderize meat and, if done properly, will do very little, toughening. Therefore, for the purposes of this study, it was deemed unnecessary to freeze-dry the meat. This permitted simplification of the experimental design.

Results and Discussion

The average results for five runs of tenderness, cuttability, and shear are shown in Tables 1, 2, and 3. The results for flavor are shown in Table 4. As was expected, there was a considerable scatter of data due to variations between individual samples of meat although the average of the raw data for five runs produced quite smooth curves for each temperature. Previous studies in this series showed the same type of results which can be attributed in general to the deliberate use of meat as received from commercial sources with no control other than U. S. Grade designation and condition. For Armed Services procurement, it would be impractical to require that meat be obtained or processed outside of recognized commercial limits unless overriding military necessity required it. The current studies are designed with this in mind.

However, data scatter does emphasize the wide variations in tenderness found from animal to animal and the value of long range studies concerned with producing tender meat through selective breeding, feeding, and other factors.

The correlation coefficients for tenderness, cuttability, and shear press at the various cooking temperatures and over-all are shown in Table 5. The correlations for tenderness and shear press, and cuttability and shear press are not significant at 140° and 160°F. This can be explained by the fact that there is very little if any change in tenderness or cuttability with time at these temperatures. The over-all correlations are excellent and show that the panel and the shear press are measuring much the same thing.

Curves were fitted to the data by the method of least squares and are shown in Figures 1, 2, and 3. Equations for the curves are shown below where t = time in hours, y_1 = mean rating scores for tenderness, y_2 = mean rating scores for cuttability, and y_3 = mean pounds pressure for shear press.

Tenderness

| Temp °F. | Equation | 95% Confidence limits |
|----------|--|-----------------------|
| 140 | $y_1 = 5.8282 - 0.0012t + 0.0002t^2$ | ± 0.4058 |
| 160 | $y_1 = 5.13 + 0.36t + 0.05t^2$ | ± 0.47 |
| 180 | $y_1 = 4.30 + 0.30t - 0.01t^2$ | ± 0.87 |
| 190 | $y_1 = 4.22 + 0.42t - 0.01t^2$ | ± 0.60 |
| 200 | $y_1 = 4.31 + 0.78t - 0.05t^2$ | ± 0.62 |
| 210 | $y_1 = 4.06 + 2.31t - 0.50t^2 + 0.01t^3$ | ± 1.24 |

Cutability

| Temp. °F. | Equation | 95% Confidence limits |
|-----------|--|-----------------------|
| 140 | $y_2 = 5.6397 - 0.0769t + 0.0074t^2$ | ± 0.4793 |
| 160 | $y_2 = 5.43 - 0.41t + 0.005t^2$ | ± 0.25 |
| 180 | $y_2 = 4.19 + 0.37t - 0.01t^2$ | ± 0.48 |
| 190 | $y_2 = 4.22 + 0.73t - 0.04t^2$ | ± 0.52 |
| 200 | $y_2 = 3.90 + 1.03t - 0.07t^2$ | ± 0.30 |
| 210 | $y_2 = 3.99 + 2.43t - 0.50t^2 + 0.04t$ | ± 0.39 |

Shear Press

| Temp. °F. | Equation | 95% Confidence limits |
|-----------|-------------------------------------|-----------------------|
| 140 | $y_3 = 325.71 + 33.20t - 4.32t^2$ | ± 29.31 |
| 160 | $y_3 = 391.50 + 25.64t - 4.57t^2$ | ± 29.07 |
| 180 | $y_3 = 463.96 - 58.96t + 4.82t^2$ | ± 67.61 |
| 190 | $y_3 = 441.09 - 78.92t + 5.61t^2$ | ± 18.79 |
| 200 | $y_3 = 440.13 - 98.35t + 7.61t^2$ | ± 55.46 |
| 210 | $y_3 = 144.9928 + 312.82 (0.4022)t$ | ± 47.64 |

A range test method was used to determine extreme values among the shear press measurements. The control limits for observations are as follows:

| n (Observations) | Range |
|---------------------|-------|
| 2 | 151 |
| 3 | 178 |
| 4 | 192 |
| 5 | 201 |

For the present study, with three shear values obtained for each sample, any value outside of the range 178 should be rejected as an extreme value.

The initial effect of heat on the meat was a toughening and, as the temperature was increased, the degree of toughening increased. After the initial toughening, which occurred very rapidly, the resulting tenderness depended upon temperature and time. If the temperature was below 180° F., time resulted in little or no tenderizing. If the temperature was 180° F. and above, the meat became tender at a rate and to a degree dependent upon both time and temperature. In general, these results confirm the practice of using internal temperatures as a measure of the degree of cooking up to a point. However, it should be kept in mind that temperature gradients across a piece of meat will very definitely cause tenderness gradients. Furthermore, temperatures of 180° F. and above will tenderize the toughened meat with time.

In general the color of the cooked meat depended upon temperature and not upon time. Samples held at an internal temperature of 140° F. for seven hours still had the appearance of rare meat. Samples held at an internal temperature of 160° F. for seven hours generally still had the pink tinge of medium done meat.

Bambett et al (11) have pointed out that it is generally assumed protein coagulation in meat takes place between 57° C. (135° F.) and 75° C. (167° F.) and that there is probably no specific coagulation temperature since muscle fibers consist of several different proteins each with a different coagulation temperature. The initial toughening of the meat is due to protein coagulation and the increase in toughness with increased temperature to progressive coagulation of the various muscle fiber proteins and the physical changes accompanying it. The average tenderness ratings for meat held at 140° F. were always higher than those

for meat held at 160° F. It is therefore apparent that some of the proteins in the meat processed at 140° F. were not coagulated even at the end of seven hours.

Further evidence pointing toward protein coagulation as being the main cause of the texture effects found in this study is shown in the shear press results. The average shear press value for raw meat was 122 pounds (average of 48 determinations), the average for meat just heated to 140° F. was 328 pounds, and meat just heated to 160° F. was 382 pounds. Shear press values for heated meat equivalent to those found with raw meat were only obtained after processing for at least seven hours at temperatures above 200° F. Furthermore, the shear press value for raw meat was always well within the range considered highly tender by the panel. This would indicate that the connective tissue in the samples submitted for evaluation in this study was not tough and that toughness found after application of heat was due to coagulation of protein.

However, due to the experimental methods used, no firm conclusions as to influence of connective tissues on over-all toughness can be drawn from this study. Since a single muscle was used throughout and large pieces of connective tissue, gristle, etc. were removed before evaluations, it could be assumed that any effects were fairly constant. Cover (12) has pointed out that connective tissue in beef loin roasts is so tender that different cooking conditions showed no difference in tenderness whereas the connective tissue in bottom round required extensive cooking to tenderize. The results were obtained by asking a

panel to evaluate tenderness of the connective tissue, friability of muscle fibers, and softness rather than rating just tenderness. However, the results of Winegarden et al (8), who showed that connective tissue is tenderized quite rapidly at temperatures above 65°C., and the type of curves currently obtained in this study strongly suggest that most of the texture effects found were due to protein coagulation and subsequent softening upon the application of heat rather than to differences in connective tissues. It is possible that these results would not hold if the samples used had been from cuts in which connective tissue is more predominant.

The results of this study combined with isolated rehydration observations indicate that more basic information should be obtained regarding the effect on the meat tissues of rehydration of cooked freeze-dried meats with hot water. On one hand this study would indicate the possibility of uncoagulated protein being present in meat cooked to internal temperatures of 150 to 160°F. which would coagulate and toughen when the hot water of rehydration was added. On the other hand, limited informal studies show that freeze-dried rare or medium done beef is not toughened by rehydration with cold water and, furthermore, upon heating after rehydration, will not be as tough as it would have been if rehydration had been accomplished with hot water. However, beef which has been subjected to the more severe cooking cycles shows little, if any, differences between the cooked product, product rehydrated with cold water, and product rehydrated with hot water. In any event, this study confirms previous results that beef cooked to internal temperatures of 150° to 160°F. will have borderline or unacceptable

average tenderness values for purposes of the Quick-Serve meals.

Since rehydration with hot water is a requirement for these meals, additional toughening by rehydration with hot water will tend to make the products completely unacceptable. With the present state of knowledge, cooking the beef with the more severe cycles is the only practical way of preparing it with acceptable tenderness for use in the Quick-Serve meals.

When this study was conceived originally it was hoped that, if time and temperature were the factors controlling tenderness in cooked meat, a formula could be developed to equate cooking cycles to resulting tenderness. This would permit translation of the tenderness results from one cooking cycle to results which could be expected from another. However, it is evident that much more data would be required before such a formula could be developed successfully.

No off-flavors were found with the severest cooking cycles although average preferences dropped slightly. This tends to confirm previous results and indicates that the more severe cycles can be used for Quick-Serve meals formulations with appropriate gravies and sauces. It had been considered possible that the longer cooking cycles would cause the meat to fall apart particularly since there was no compression during or after cooking. However, no trouble was experienced except with the sample at 210°F. for seven hours which fell apart so badly it could not be evaluated.

This study was not concerned with the most acceptable tenderness, but rather with the effect of time and temperature on tenderness. The panel was instructed to ignore individual preferences in judging the

tenderness of the sample and to judge only the degree of tenderness. Therefore, it should not be assumed that any particular cooking cycle is recommended by the panel or by this study. On the contrary, in several instances the panel members rated samples "extremely tender" but did not care for the extremely soft textures and expressed opinions that the meat was "mealy."

Conclusions

It is evident that the degree of tenderness of cooked beef attained through cooking is dependent upon both time and temperature as well as the inherent tenderness of the meat. The initial effect of heat is a toughening which is due to protein coagulation progressively occurring over a temperature range. Tenderness of the meat at this stage is a function of temperature and the inherent tenderness of the meat with time having little or no effect. Once coagulation and accompanying physical changes are complete, the meat is at its toughest state. Tenderization with further cooking is a function of time and temperature. Temperatures below 180°F. will accomplish little or no tenderization whereas temperatures of 180°F. and above will cause tenderization as a function of time and temperature.

There was no evidence in this study that connective tissue played an important part in the cooked meat toughness. Shear press results with the raw meat were always much lower (more tender) than with even meat just heated to 140°F. and were always in the shear press range considered very tender by the panel. It is entirely possible that an investigation of other meat cuts, particularly cuts containing more

connective tissue, would show different results.

Kramer shear press results correlated very highly with panel ratings for both tenderness and cuttability although their correlation with cuttability was slightly higher than with tenderness scores. As was found with previous studies careful selection of samples and standardization of techniques are necessary for reproducible results.

The wide scatter of data found in this study as well as in previous studies indicates that meat obtained from commercial sources varies widely in the tenderness obtained by a given cooking cycle and emphasize the value of studies directed toward improving the inherent tenderness of the meat. The low average tenderness ratings for less severe cooks confirms that more severe cooks should be used to produce a product with over-all acceptable tenderness for the Quick-Serve meals when the meat is obtained from commercial sources even though such cooks result in somewhat lower ratings for flavor and juiciness. The alternative of using the more tender cuts from the better grades of beef is considered unacceptable because of the increased cost and excessive fat content.

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Table 1

Tenderness means on 9-point rating scale
(Average of 5 runs)

| Temperature °F. | Heating Time (Hours) | | | | | | | |
|--------------------|----------------------|-----|-----|-----|-----|-----|-----|-----|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 140 | 5.9 | 5.7 | 5.8 | 6.0 | 6.0 | 5.6 | 5.9 | 5.9 |
| 160 | 5.1 | 4.8 | 4.7 | 4.4 | 4.2 | 4.5 | 4.9 | 4.7 |
| 180 | 4.5 | 4.1 | 5.2 | 5.0 | 5.7 | 5.3 | 5.7 | 6.1 |
| 190 | 4.4 | 4.5 | 4.8 | 5.5 | 5.7 | 6.4 | 6.3 | 6.5 |
| 200 | 4.2 | 4.8 | 4.9 | 6.3 | 6.5 | 6.8 | 6.8 | 7.3 |
| 210 | 4.0 | 5.9 | 6.9 | 7.4 | 7.6 | 7.7 | 7.9 | -- |

Table 2

Cutability means on 9-point rating scale
(Average of 5 runs)

| Temperature °F. | Heating Time (Hours) | | | | | | | |
|--------------------|----------------------|-----|-----|-----|-----|-----|-----|-----|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 140 | 5.7 | 5.4 | 5.5 | 5.6 | 5.5 | 5.2 | 5.7 | 5.4 |
| 160 | 5.4 | 5.1 | 4.9 | 4.6 | 4.6 | 4.6 | 5.0 | 5.1 |
| 180 | 4.3 | 4.4 | 4.9 | 5.3 | 5.7 | 5.8 | 5.8 | 6.5 |
| 190 | 4.4 | 4.7 | 5.5 | 5.9 | 6.6 | 7.1 | 7.0 | 7.2 |
| 200 | 3.9 | 4.7 | 5.9 | 6.5 | 7.0 | 7.4 | 7.7 | 8.0 |
| 210 | 3.9 | 6.1 | 7.2 | 7.8 | 8.1 | 8.3 | 8.4 | -- |

Table 3

Shear Press means
(Average of 5 runs)

| Temperature °F. | Heating Time (Hours) | | | | | | | |
|--------------------|----------------------|-----|-----|-----|-----|-----|-----|-----|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 140 | 328 | 349 | 378 | 394 | 371 | 398 | 368 | 345 |
| 160 | 382 | 429 | 422 | 427 | 411 | 406 | 391 | 343 |
| 180 | 456 | 440 | 346 | 316 | 304 | 287 | 321 | 265 |
| 190 | 402 | 374 | 296 | 250 | 218 | 191 | 176 | 157 |
| 200 | 450 | 335 | 251 | 249 | 167 | 126 | 130 | 123 |
| 210 | 491 | 276 | 219 | 154 | 151 | 167 | 136 | -- |

Table 4

Flavor means on 9-point rating scale
(Average of 5 runs)

| Temperature °F. | Heating Time (Hours) | | | | | | | |
|--------------------|----------------------|-----|-----|-----|-----|-----|-----|-----|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 140 | 5.9 | 6.0 | 5.6 | 5.7 | 5.6 | 5.8 | 5.8 | 5.8 |
| 160 | 5.8 | 5.4 | 5.6 | 5.5 | 5.2 | 5.1 | 4.9 | 5.0 |
| 180 | 5.9 | 5.4 | 5.8 | 5.5 | 5.6 | 5.8 | 5.6 | 5.5 |
| 190 | 5.4 | 5.1 | 5.3 | 5.4 | 5.2 | 5.2 | 4.9 | 5.1 |
| 200 | 5.5 | 5.7 | 5.6 | 5.8 | 5.5 | 5.7 | 5.4 | 5.5 |
| 210 | 5.4 | 5.8 | 5.8 | 5.8 | 5.5 | 5.8 | 5.6 | -- |

Table 5

Correlation Coefficients (r)

| Temperature, °F. | Tenderness and Cuttability | Tenderness and Shear Press | Cuttability and Shear Press |
|------------------|-------------------------------|-------------------------------|--------------------------------|
| 140 | .765 | -.018* | -.419* |
| 160 | .904 | -.300* | -.433* |
| 180 | .937 | -.899 | -.941 |
| 190 | .980 | -.945 | -.980 |
| 200 | .989 | -.966 | -.978 |
| 210 | .998 | -.987 | -.980 |
| Over-all | .995 | -.870 | -.947 |

The r values with an asterisk are not significant ($P=.05$). All other r values are significant at $P=.05$.

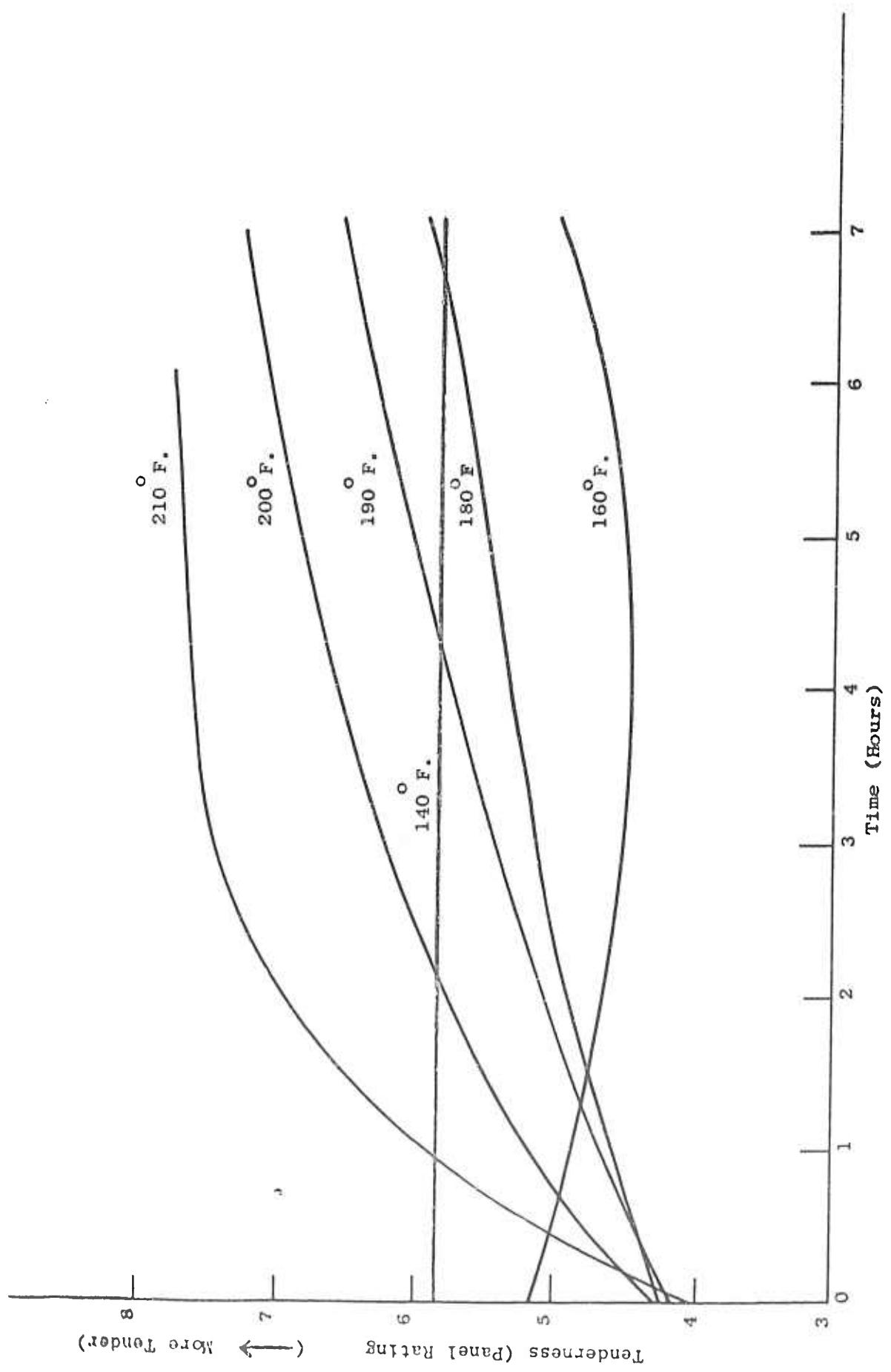


Figure 1
Tenderness vs. Time

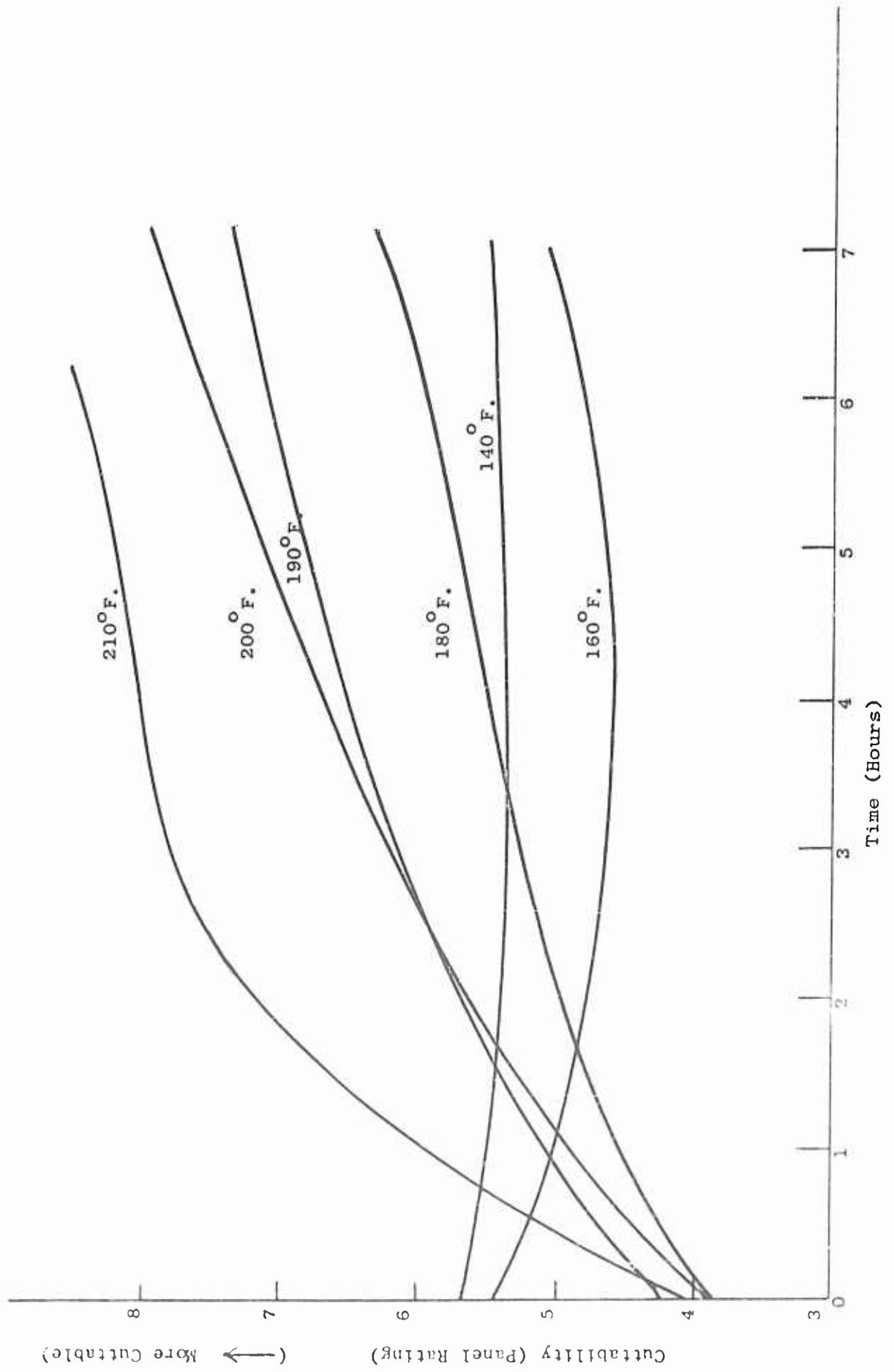


Figure 2
Cutability vs. Time

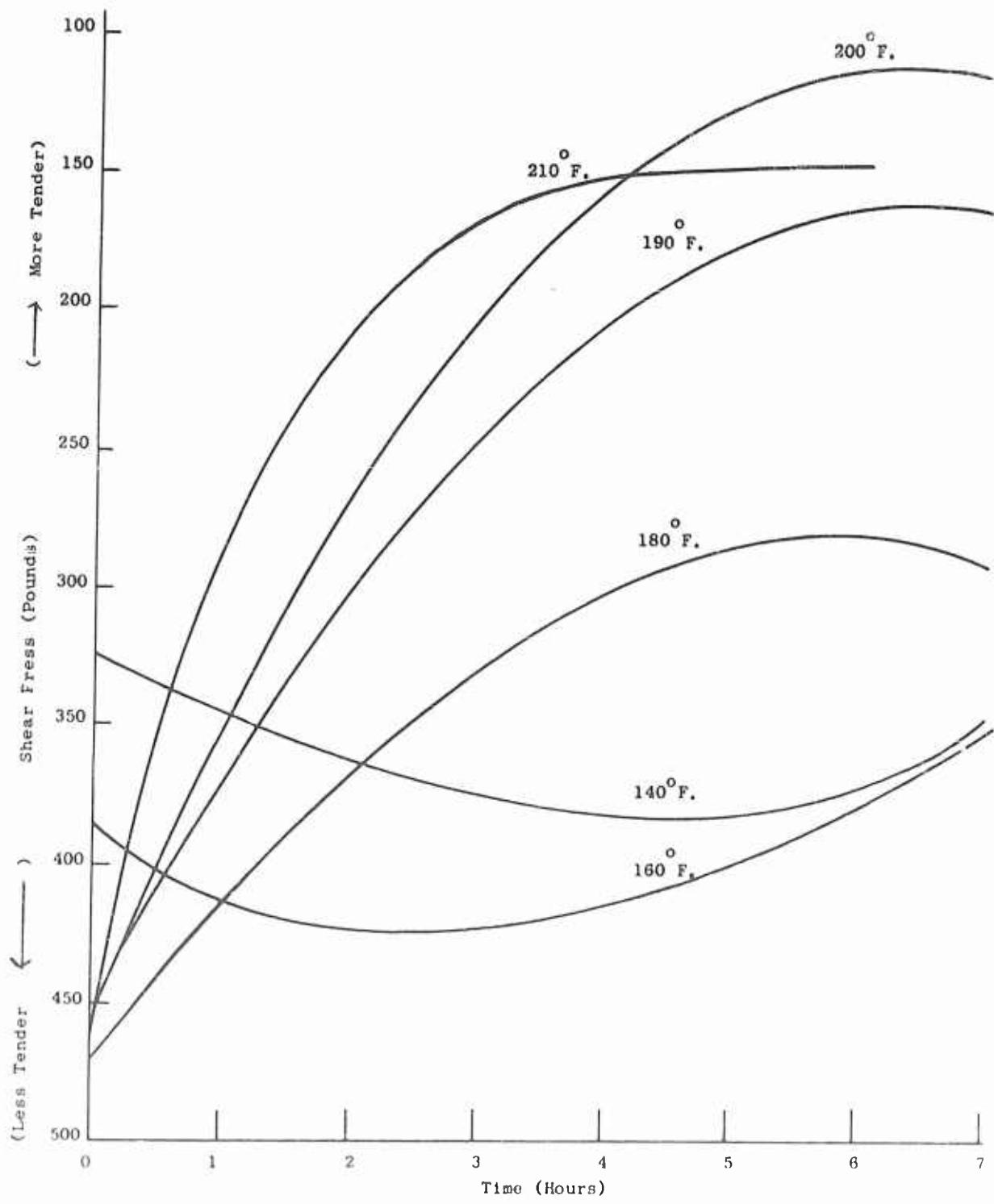


Figure 3
Shear Press vs. Time
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